

A Statistical Approach to Human Kinematic Response to Impact Acceleration

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Abstract: A statistical study was made of six head kinematic response curves for a set of 57 human -X impact acceleration runs conducted at the Naval Biodynamics Laboratory. The acceleration levels ranged from six to fifteen g's. Of the six responses analyzed, three measured head linear displacement and rotation in the mid-sagittal plane with respect to the sled, and three measured head linear and angular acceleration in the X-Y plane of the head anatomical co-ordinate system [1,2]. Key points characterizing each head kinematic response variable were identified and regressed on sled acceleration profile and head orientation parameters [3,4,5]. Cubic splines were fitted to the predicted kinematic response points.

Introduction: Human and rhesus head kinematic data can both be used to develop human head injury prediction models for impact acceleration environments. While human head-neck kinematics for the -X vector direction have been successfully modelled utilizing a deterministic head-neck linkage model [1,6-10] driven by accelerations at T-1, the first thoracic vertebral body, the lack of rhesus T-1 data precludes the development of a similar animal model. The large database of rhesus kinematic, injury and pre-injury data [11,12] collected at the Naval Biodynamics Laboratory requires other means for scaling human and rhesus head kinematic responses. Although no deterministic linkage model is available for the rhesus kinematics, perusal of Figures 1-14 comparing 15g -X human head kinematic responses to 89g -X rhesus head kinematic responses provides convincing visual evidence that, except for scale, the underlying structure of key human and rhesus responses is essentially the same. Since sled acceleration profiles and head initial orientation parameters are available for both human and rhesus impact acceleration runs, it was decided to determine the extent to which human and rhesus kinematic behavior regressed on these parameters. This paper presents the first stage of this study, namely, the statistical curve fitting of key human -X head kinematic response curves.

Methodology: The first step in the statistical curve fitting procedure is to identify key points, such as onset points, primary and secondary peaks, and offset points together with their times of occurrence for each key head kinematic variable (see Figures 15-

20). For data reduction purposes, an entire kinematic response curve is represented as a single vector containing key point magnitudes and times of occurrence. This vector is regressed on an input vector containing the various sled acceleration profile and head initial orientation parameters using a multivariate regression program. The mean predicted response points for a given set of input parameters is then fitted with a cubic spline to provide a predicted response curve for the particular head kinematic variable.

Results: Five variables were sufficient to predict all key points chosen with R^2 values ranging from 0.6 to 0.9. These variables were the initial linear displacements of the head in the X and Z directions, the initial rotation of the head about the head anatomical Y-axis, the peak sled acceleration and the endstroke sled velocity. Also, the R^2 values associated with the dominant peaks were generally among the highest. No statistical measure was made of the extent to which the predicted curves fit the observed, but visual comparisons (see Figures 21-26) suggest a very good fit, especially considering the small number of available data points chosen.

Conclusions: The results of this study clearly support the feasibility of a statistical approach to the scaling of human and rhesus -X head kinematics. Current analyses at the Naval Biodynamics Laboratory using more sophisticated statistical curve fitting procedures for both human and rhesus -X head kinematic responses is yielding extremely encouraging results.

Approved for public release; distribution is unlimited.

Funding Statement.

This research was sponsored by the Naval Medical Research and Development Command and performed under Work Unit No. 63216N-M0097.001.

Acknowledgement.

The authors wish to thank Mr. Ronnie Wilson of the Mathematics Division of the Naval Biodynamics Laboratory for his expert knowledge and tireless efforts in completing the necessary word processing, data processing, and graph generation for this paper. Special thanks to Mr. William Muzzy of the Engineering Division of the Naval Biodynamics Laboratory for his invaluable assistance with the graphics portion of this paper.

Disclaimer.

The interpretations and opinions in this work are the author's

and do not necessarily reflect the policy and views of the Navy or other government agencies.

Human Use Statement.

Volunteer subjects were recruited, evaluated, and employed in accordance with the procedures specified in the Department of Defense Directive 3216.2 and Secretary of the Navy Instruction 3900.39 series. These instructions meet or exceed prevailing national and international standards for the protection of human subjects.

Animal Use Statement.

The animals used in this work were handled in accordance with the principles outlined in the guide for the care and use of laboratory animals (National Institutes of Health Document No. NI4 80-23) established by the Institute of Laboratory Animal Resources, National Research Council, Bethesda, MD.

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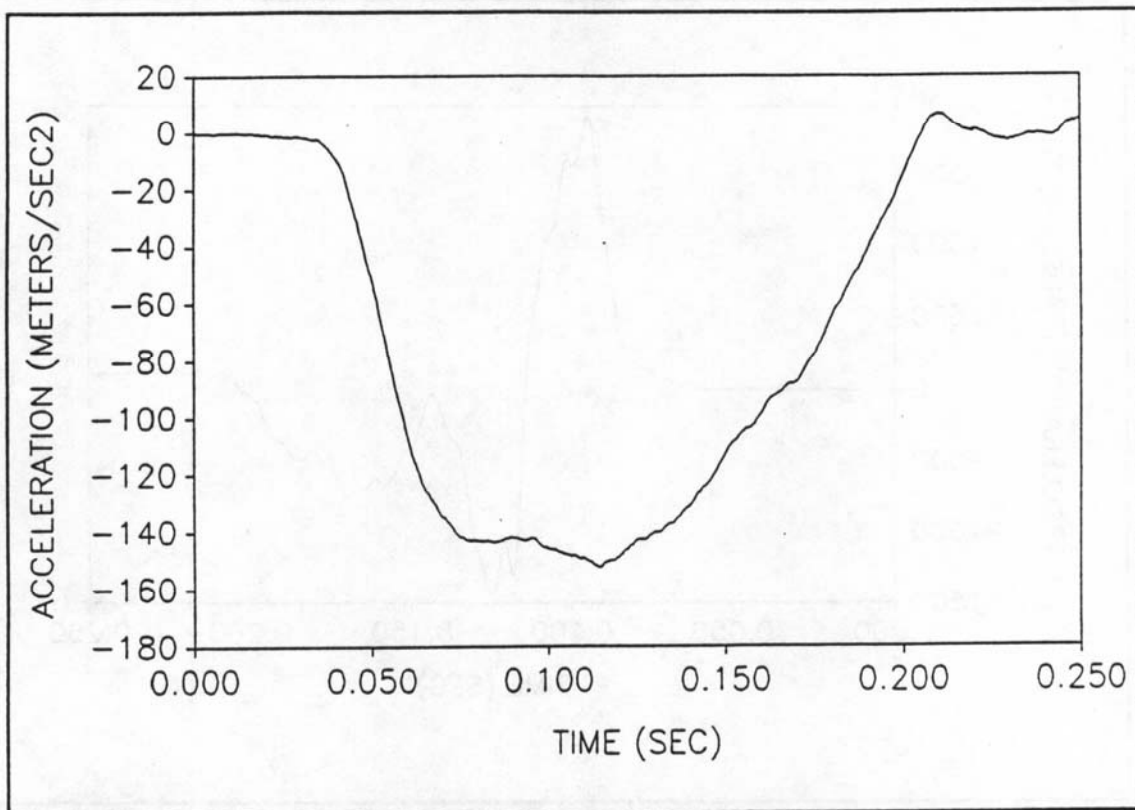


Figure 1. Sled acceleration profile for 15g, -X human run.

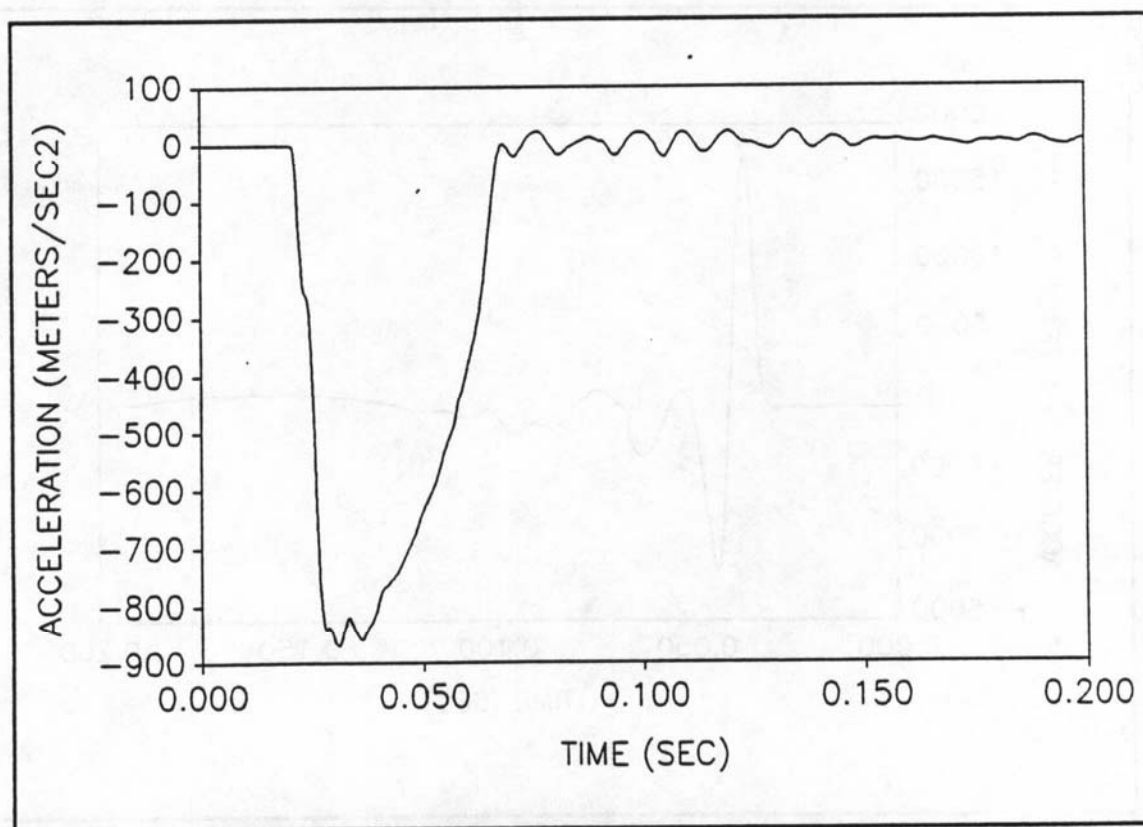


Figure 2. Sled acceleration profile for 89g, -X animal run.

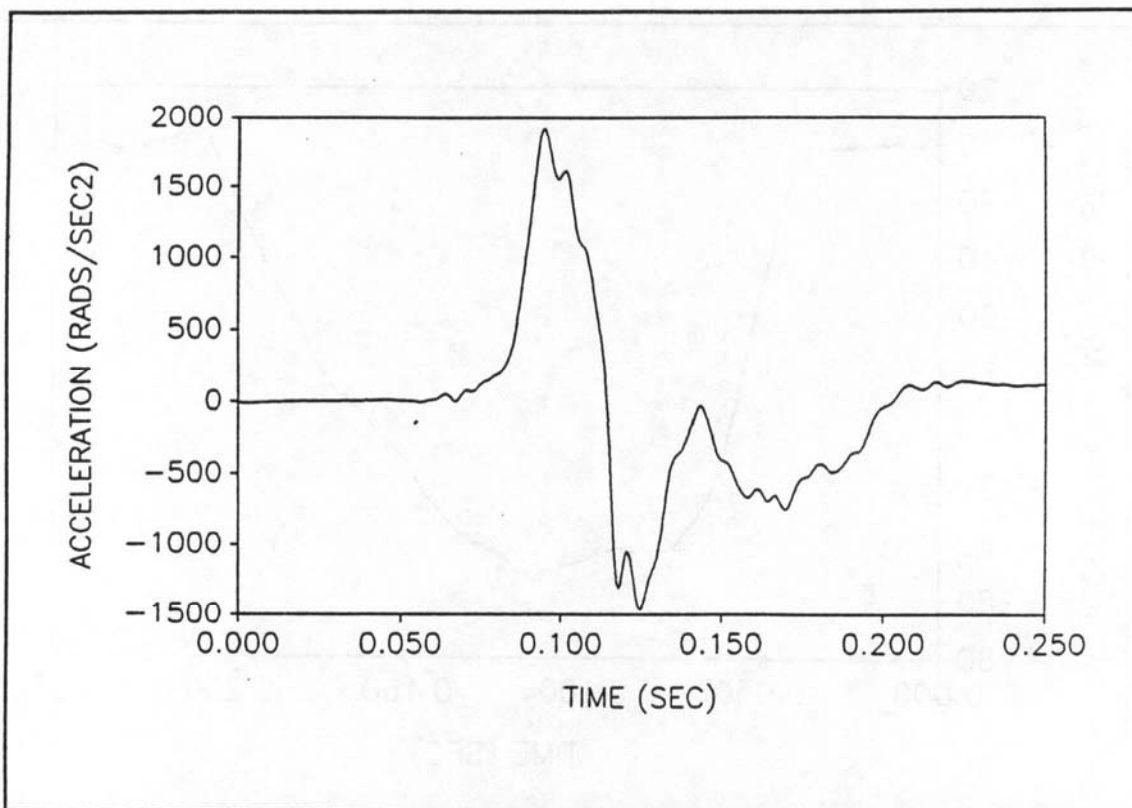


Figure 3. Y-axis component of head angular acceleration for 15g, -X human run.

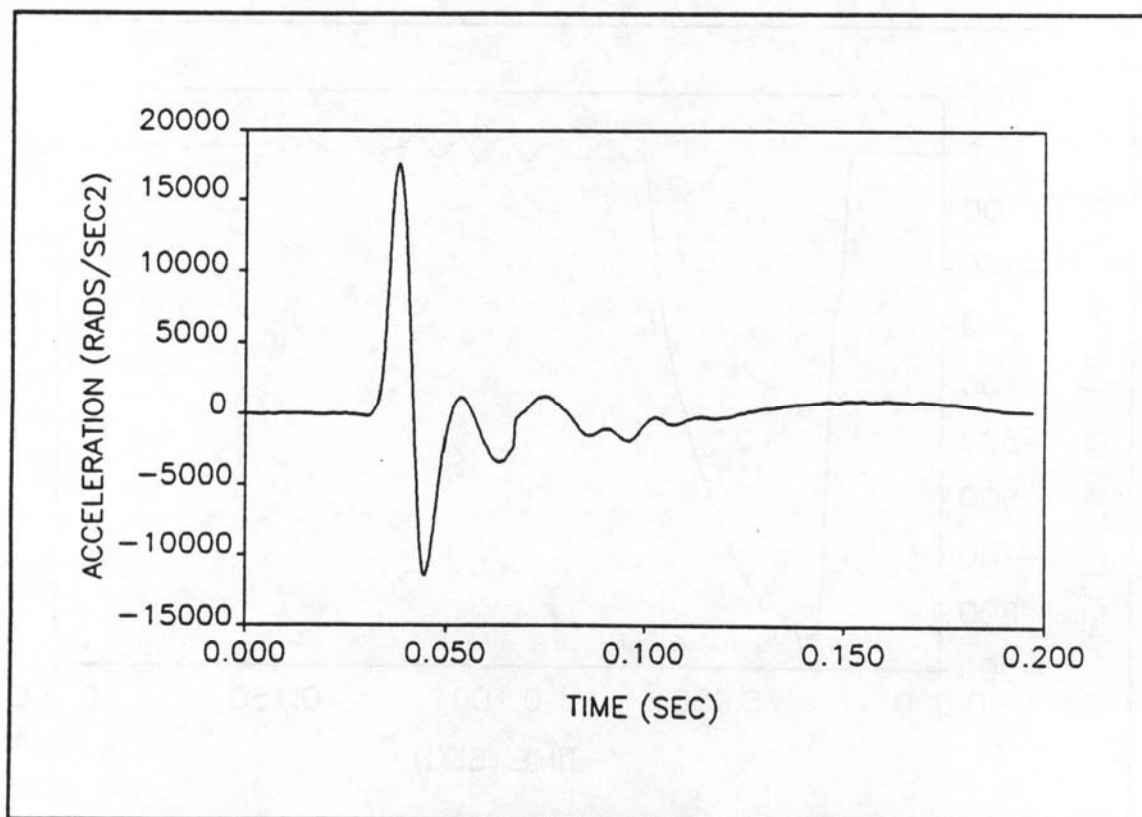


Figure 4. Y-axis component of head angular acceleration for 89g, -X animal run.

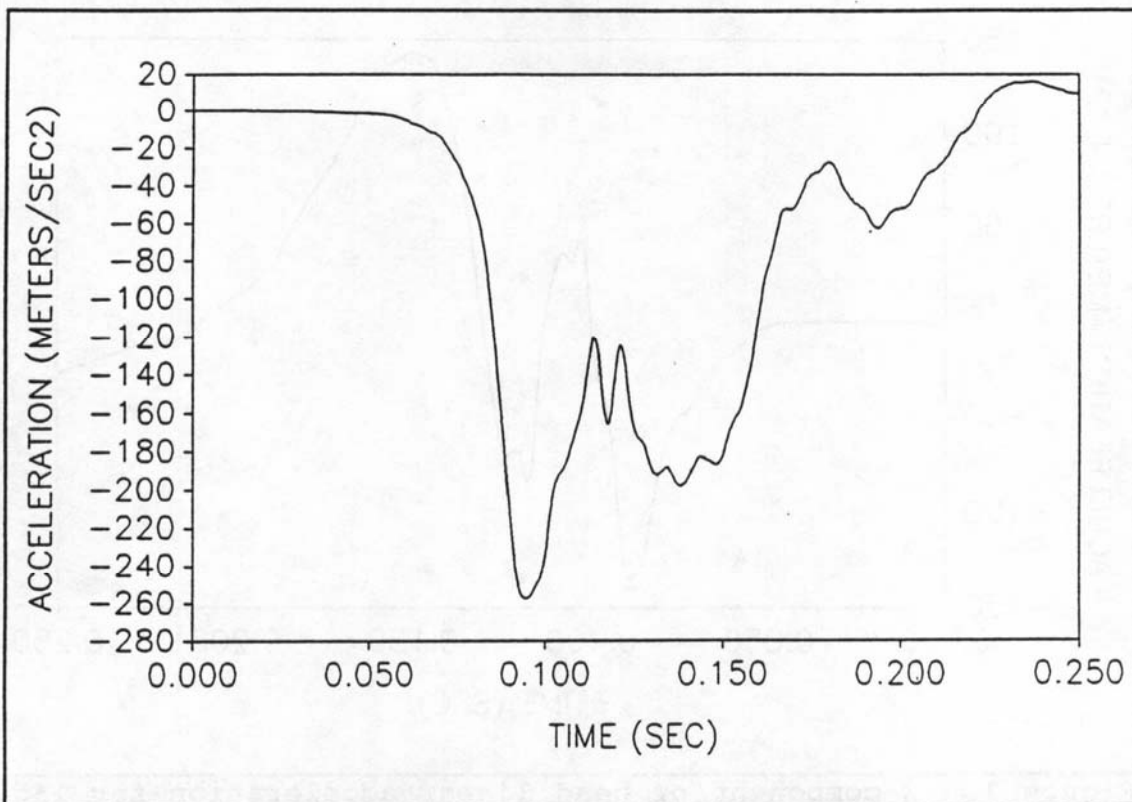


Figure 5. X-component of head linear acceleration for 15g, -X human run.

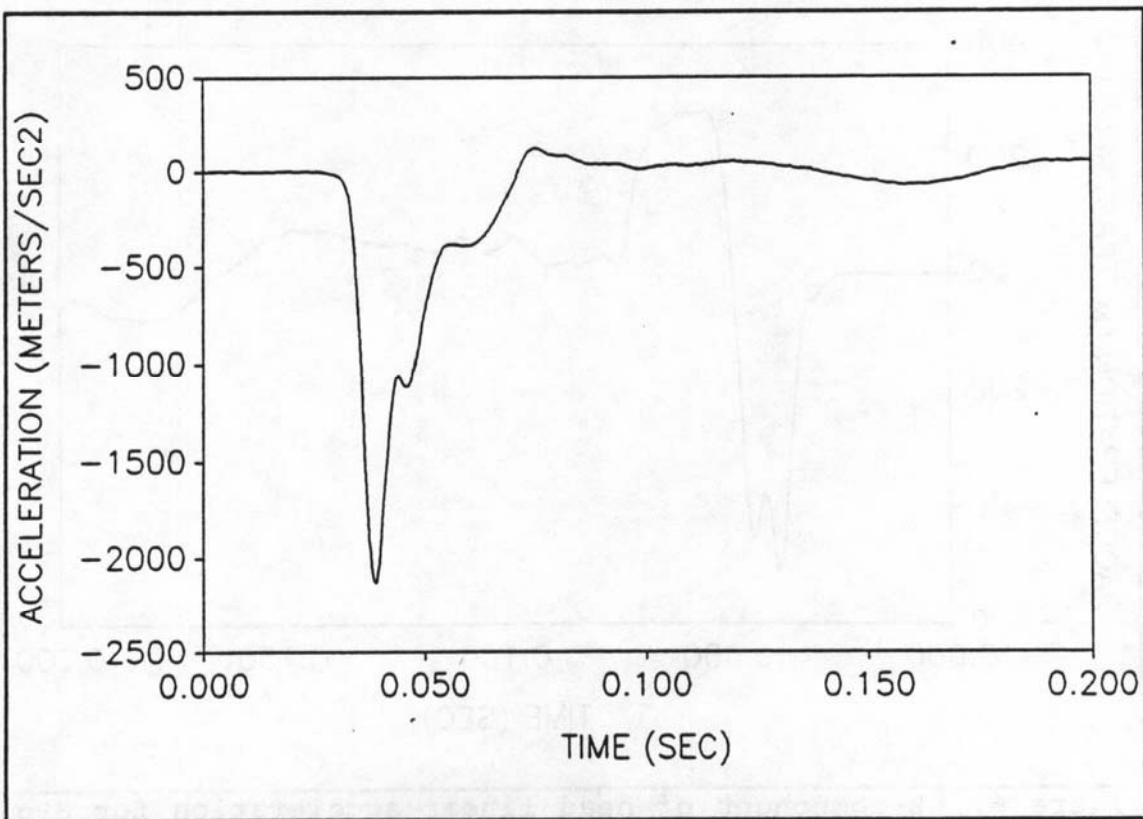


Figure 6. X-component of head linear acceleration for 89g, -X animal run.

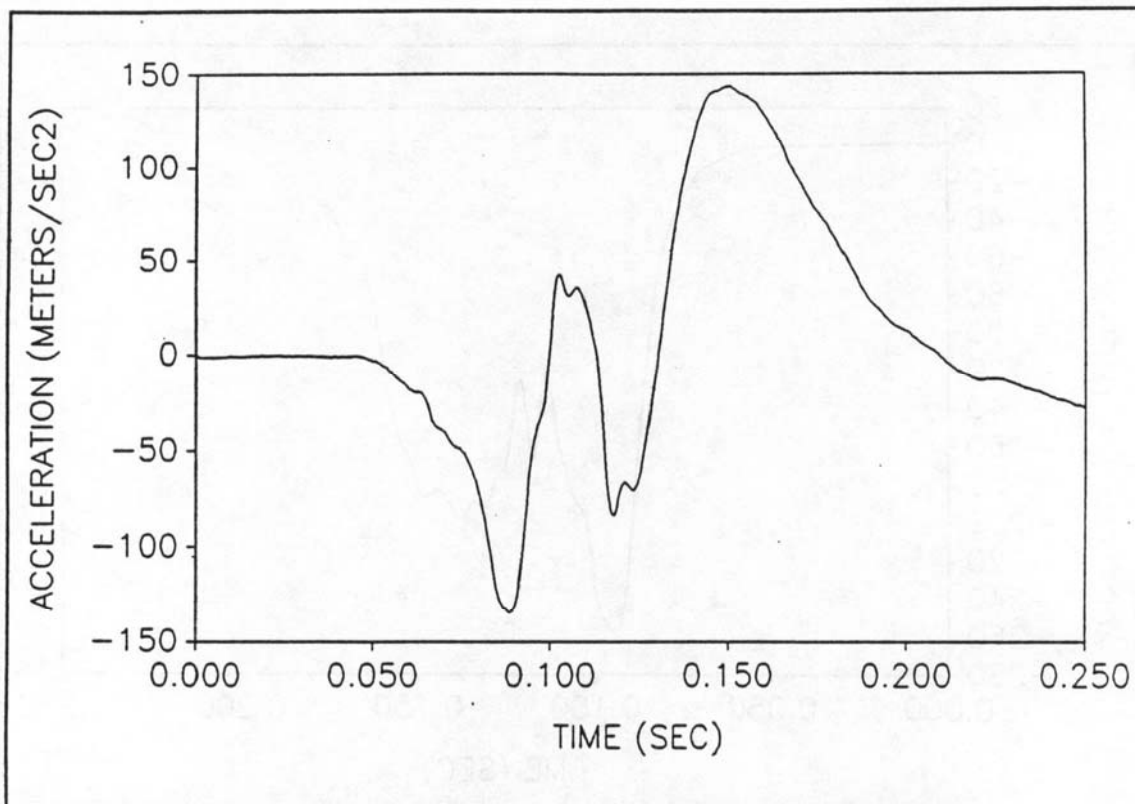


Figure 7. Z-component of head linear acceleration for 15g, -X human run.

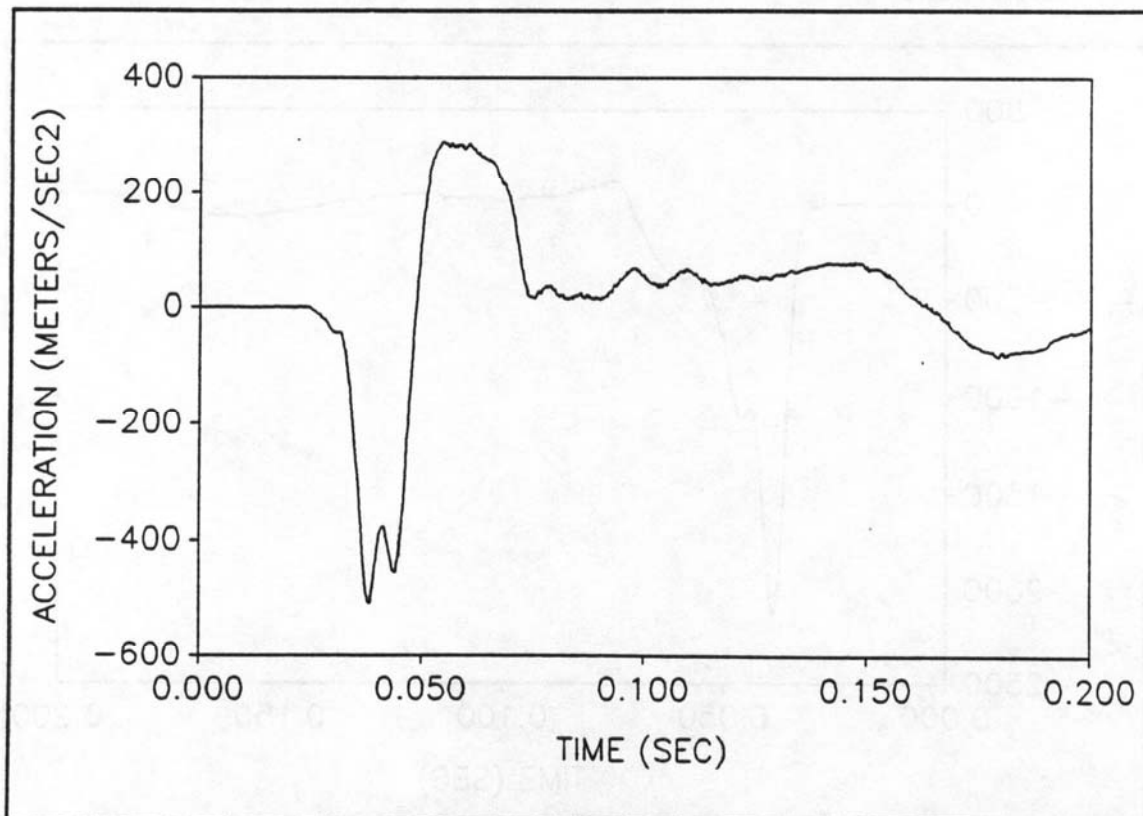


Figure 8. Z-component of head linear acceleration for 89g, -X animal run.

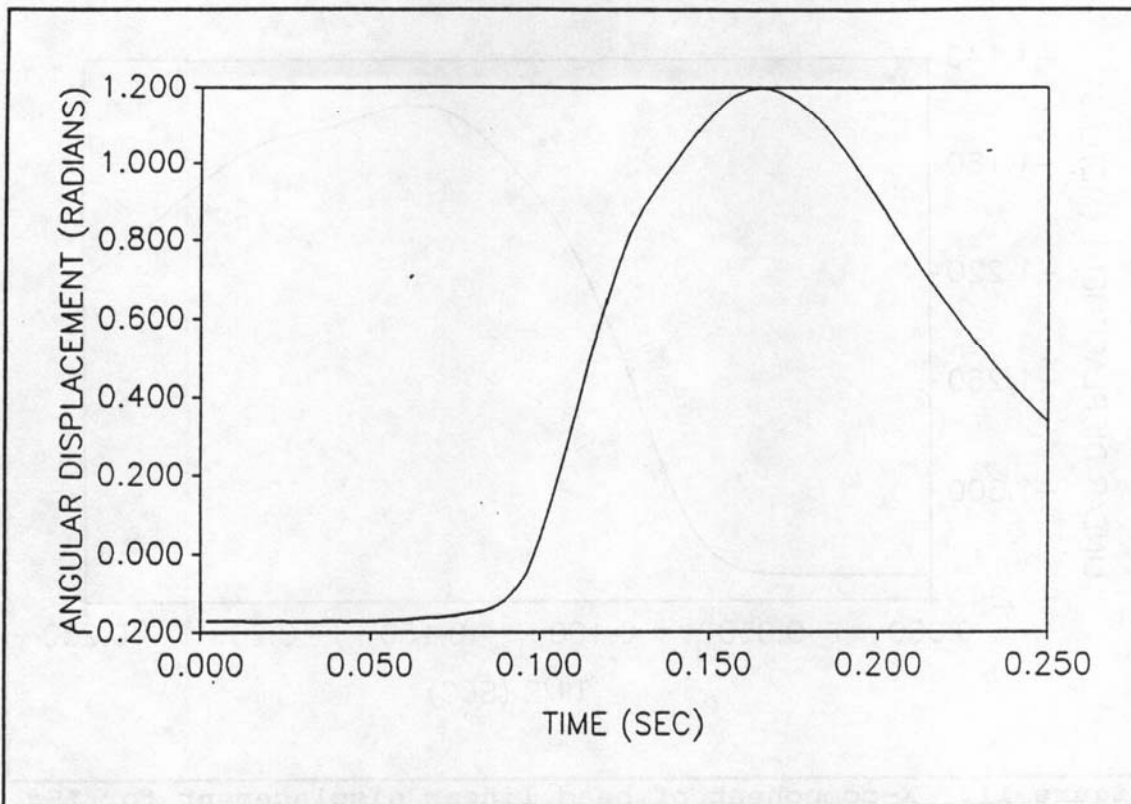


Figure 9. Y-axis component of head angular displacement for 15g, -X human run.

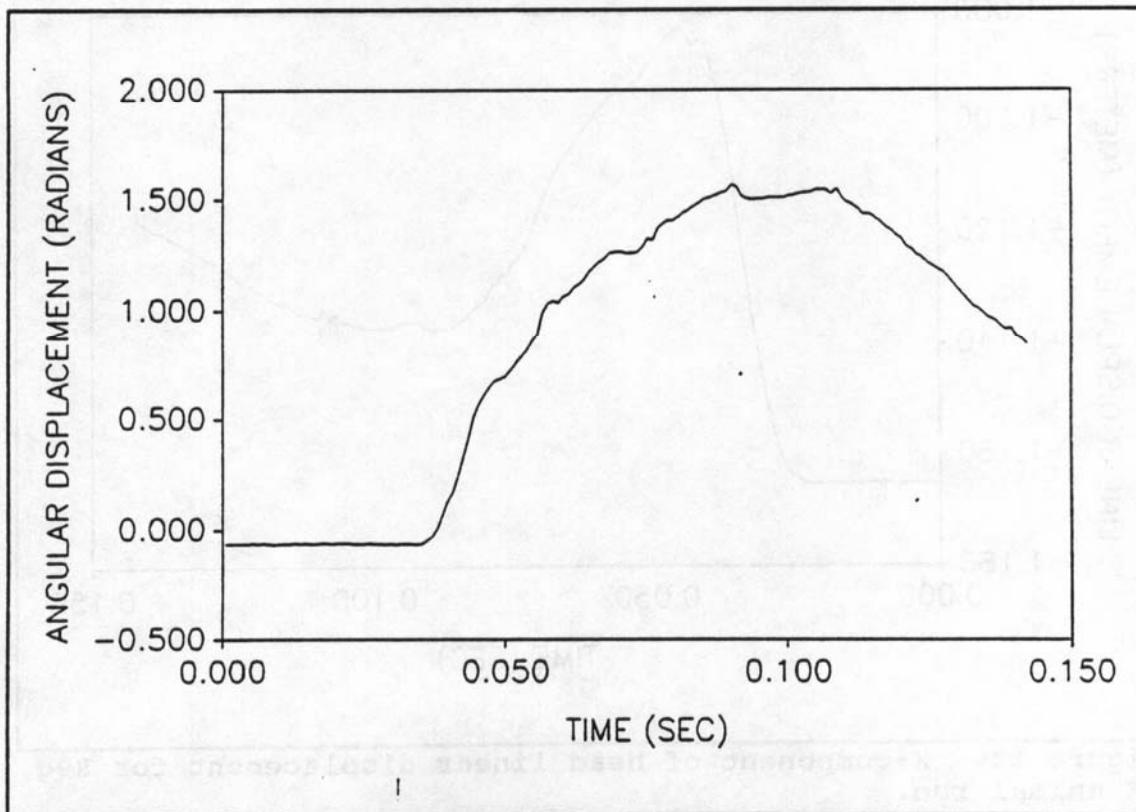


Figure 10. Y-axis component of head angular displacement for 89g, -X animal run.

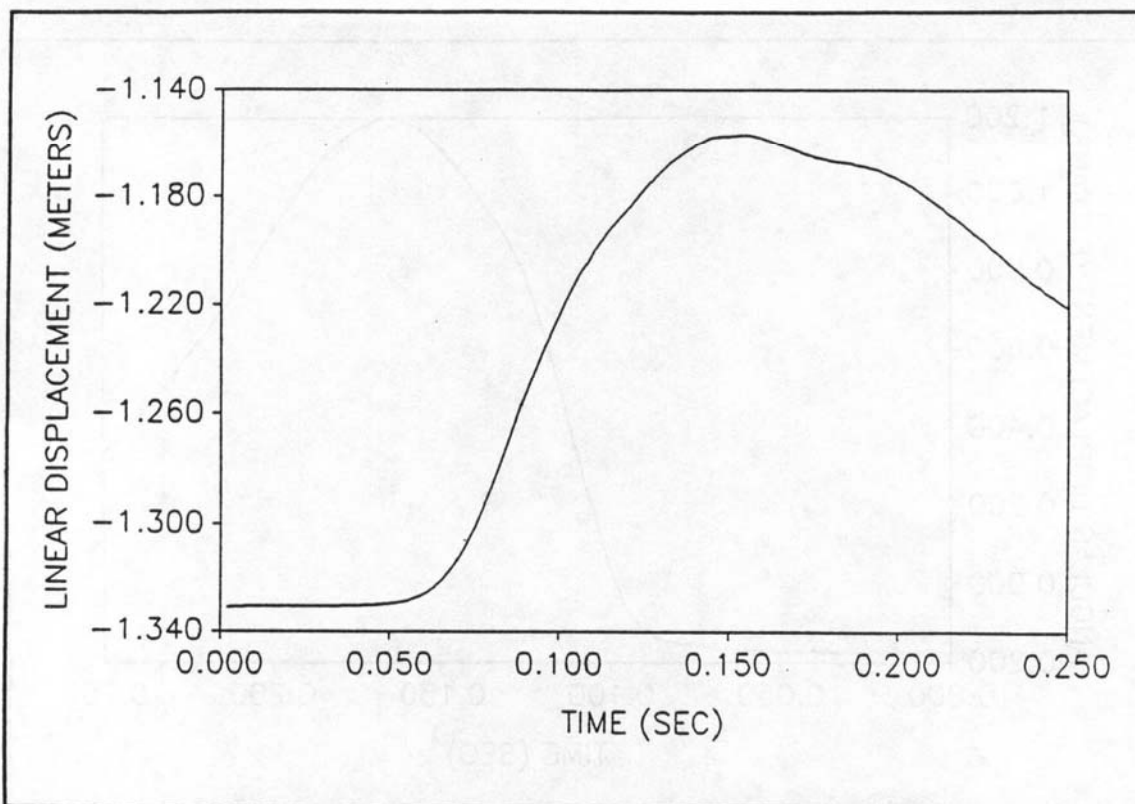


Figure 11. X-component of head linear displacement for 15g, -X human run.

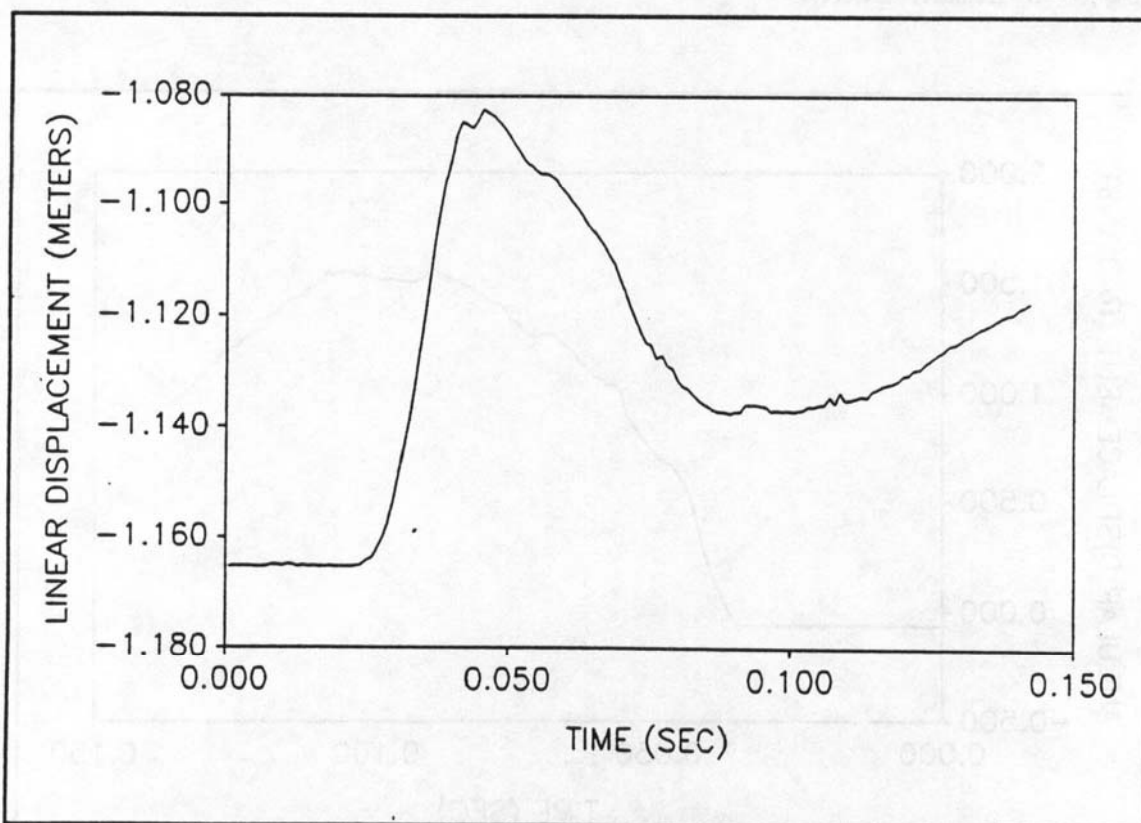


Figure 12. X-component of head linear displacement for 89g, -X animal run.

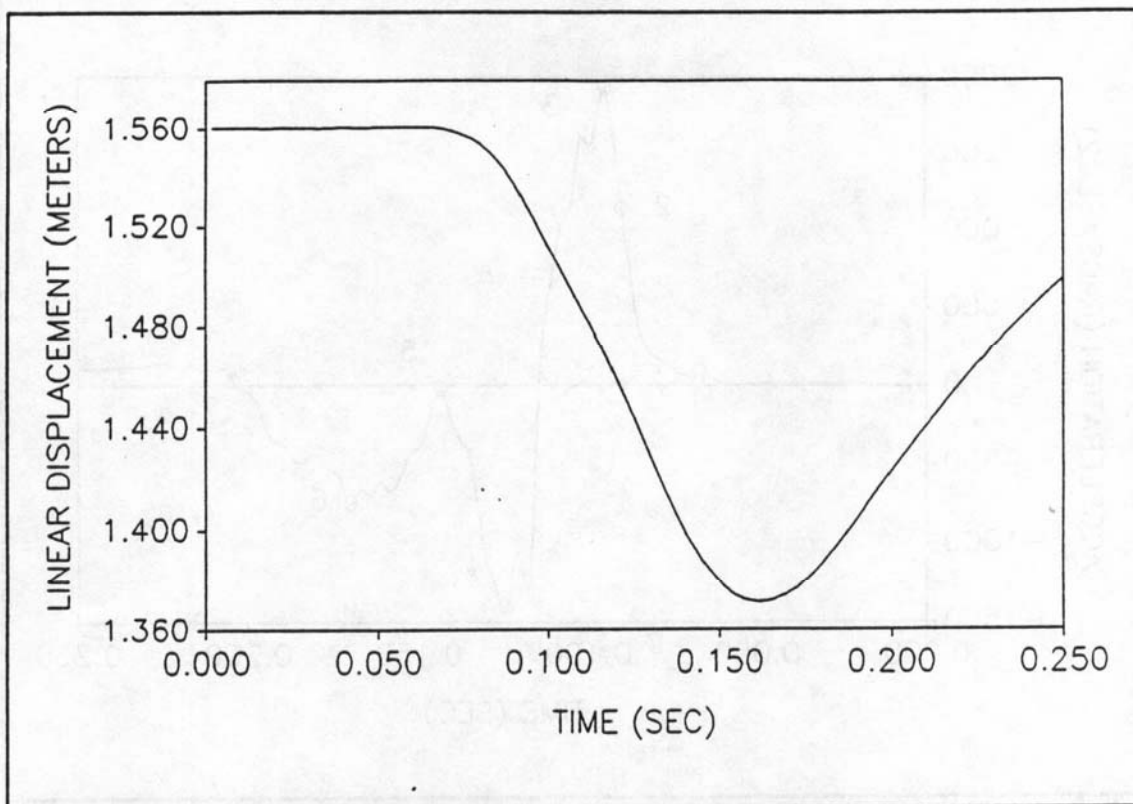


Figure 13. Z-component of head linear displacement for 15g, -X human run.

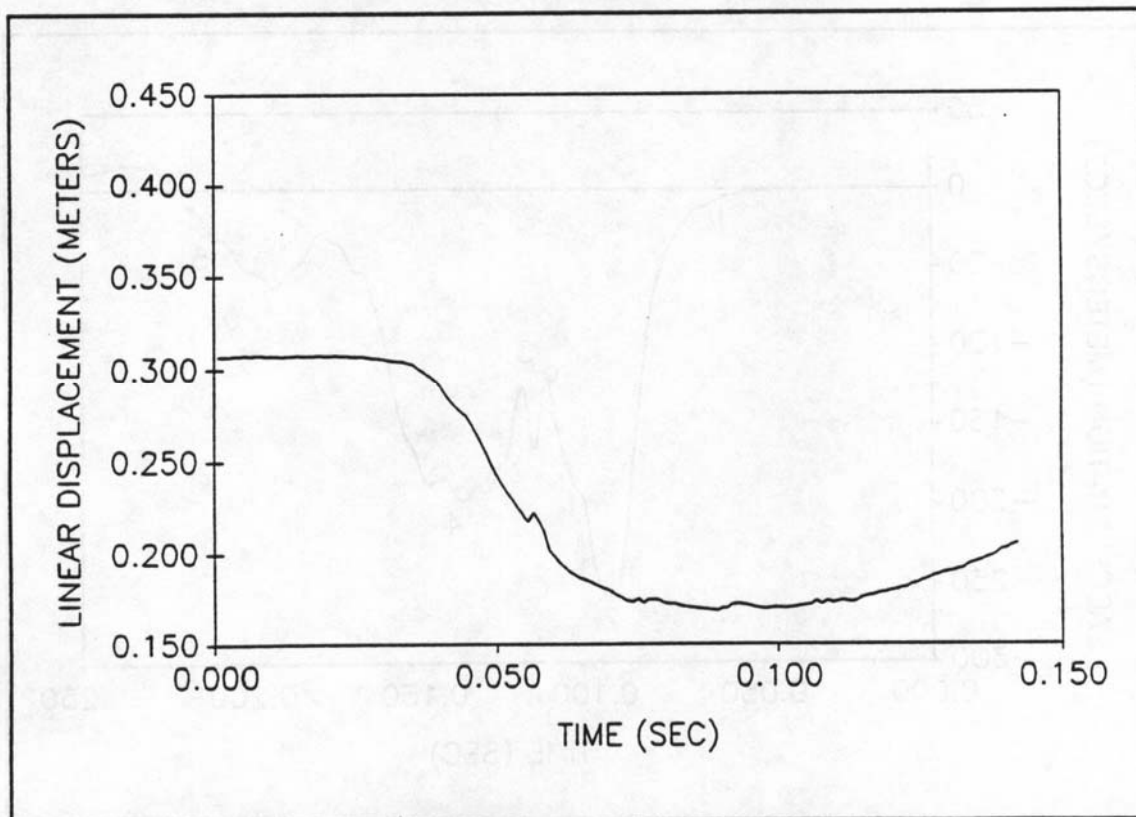


Figure 14. Z-component of head linear displacement for 89g, -X animal run.

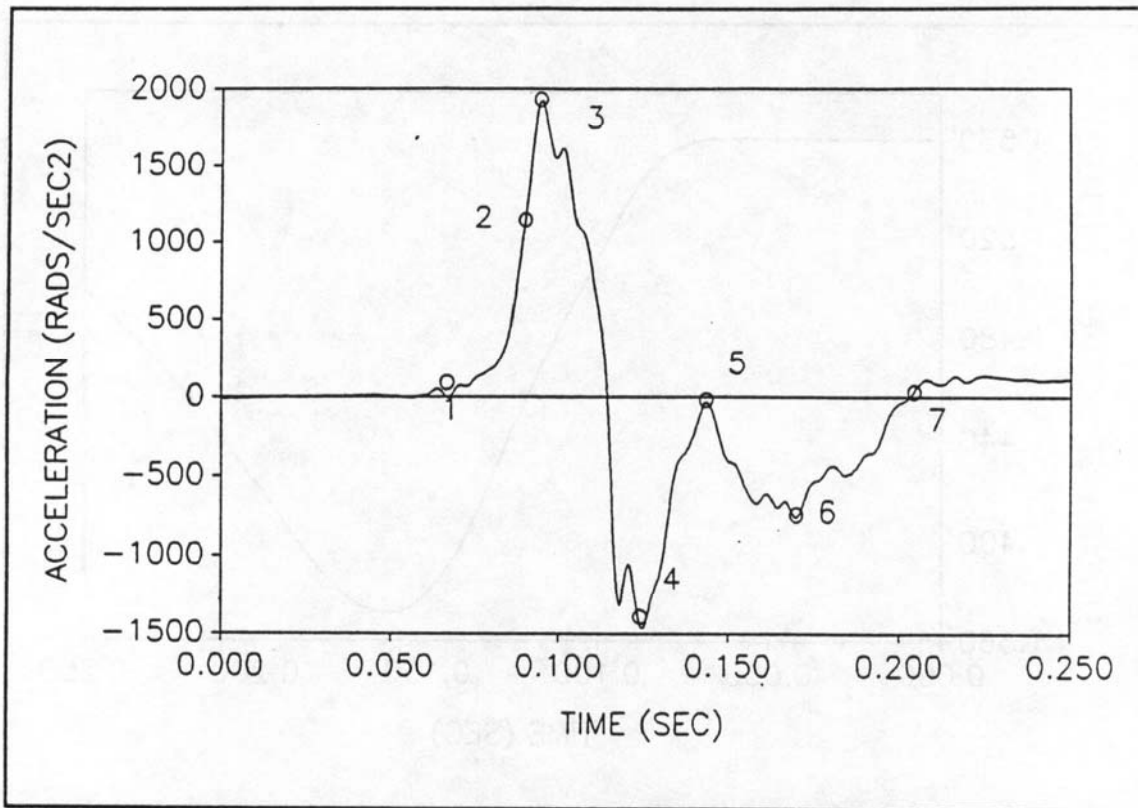


Figure 15. Onset, primary and secondary peaks, and offset points chosen for modelling the Y-axis component of head angular acceleration for 15g, -X human run.

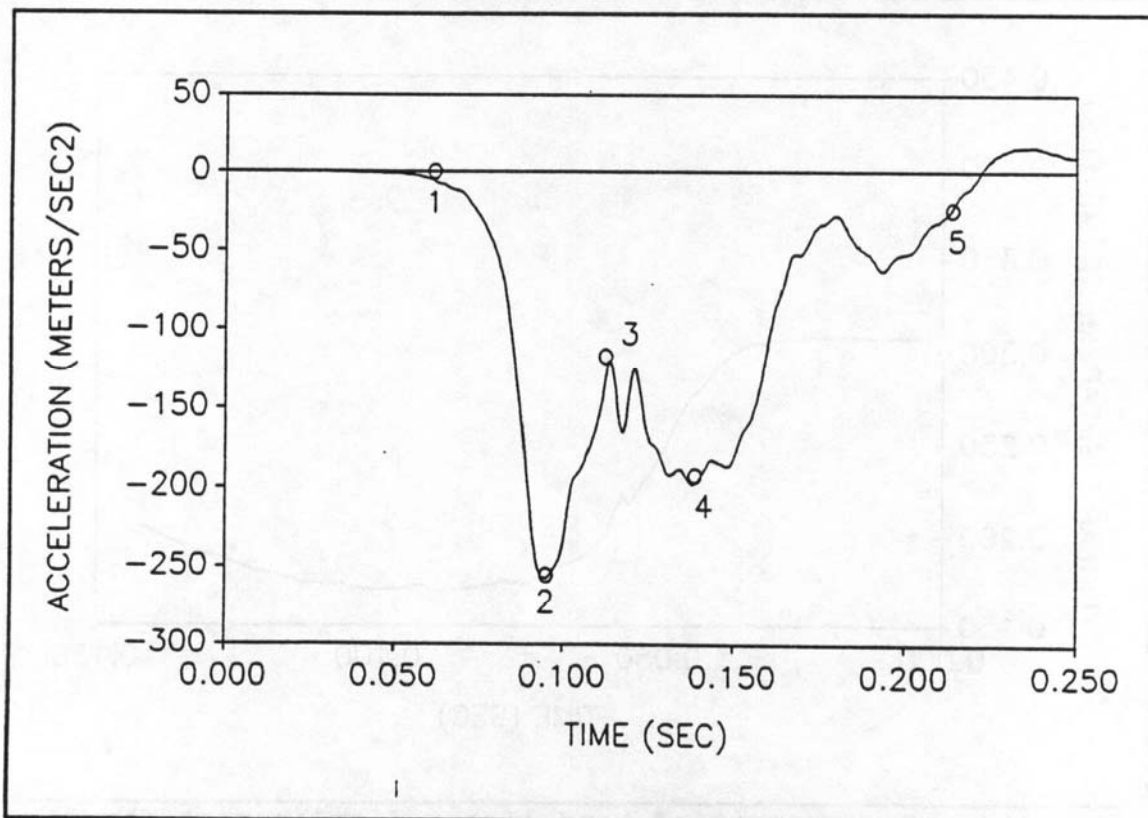


Figure 16. Onset, primary and secondary peaks, and offset points chosen for modelling the X-component of head linear acceleration for 15g, -X human run.

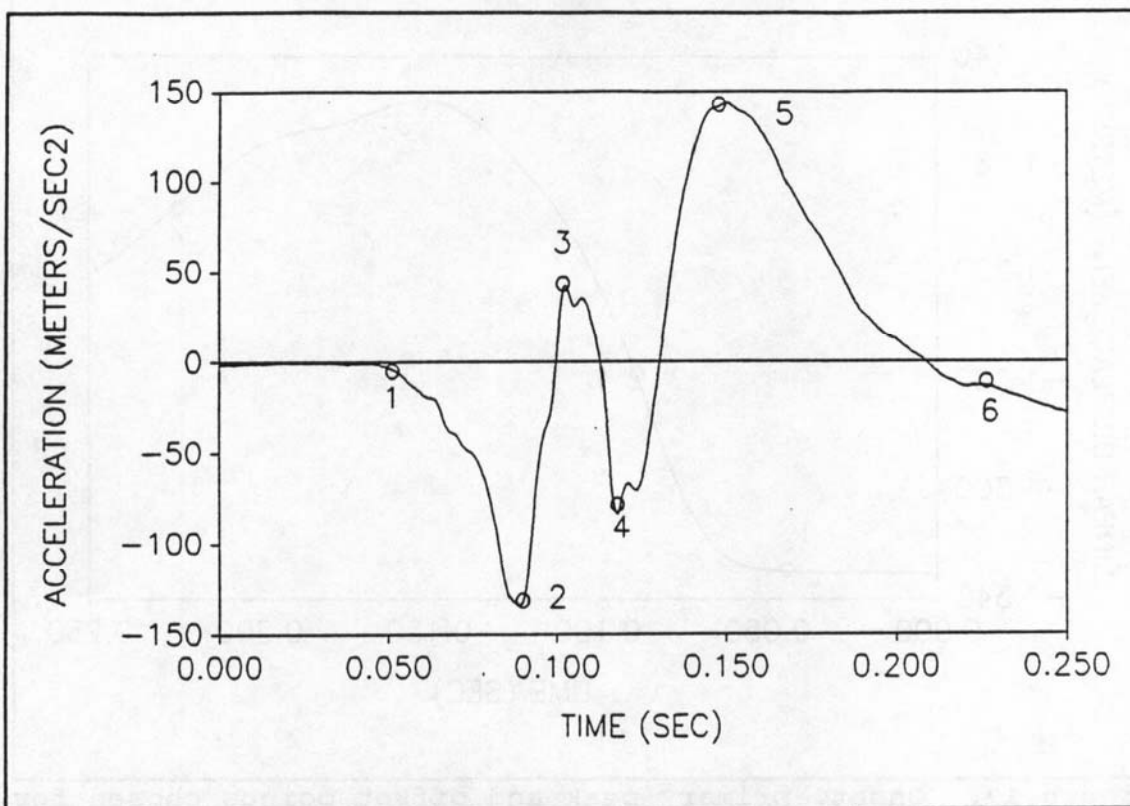


Figure 17. Onset, primary and secondary peaks, and offset points chosen for modelling the Z-component of head linear acceleration for 15g, -X human run.

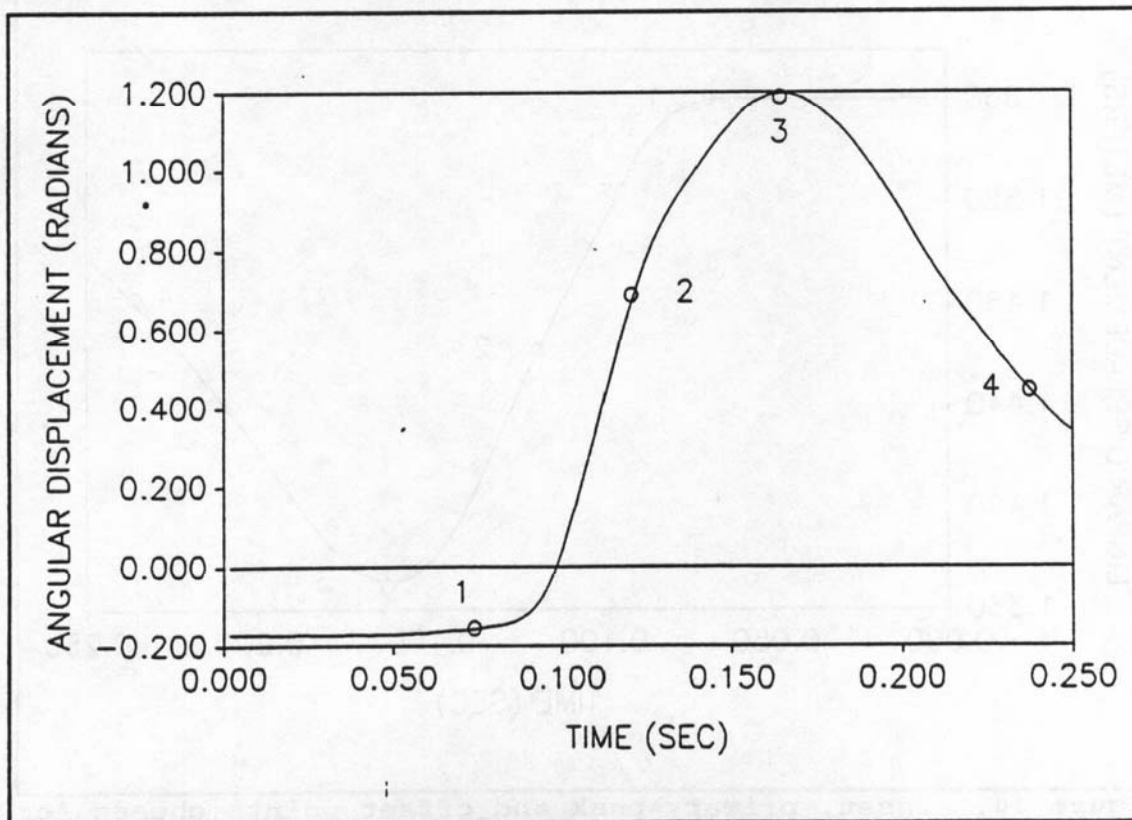


Figure 18. Onset, primary peak and offset points chosen for modelling the Y-axis component of head angular displacement for 15g, -X human run.

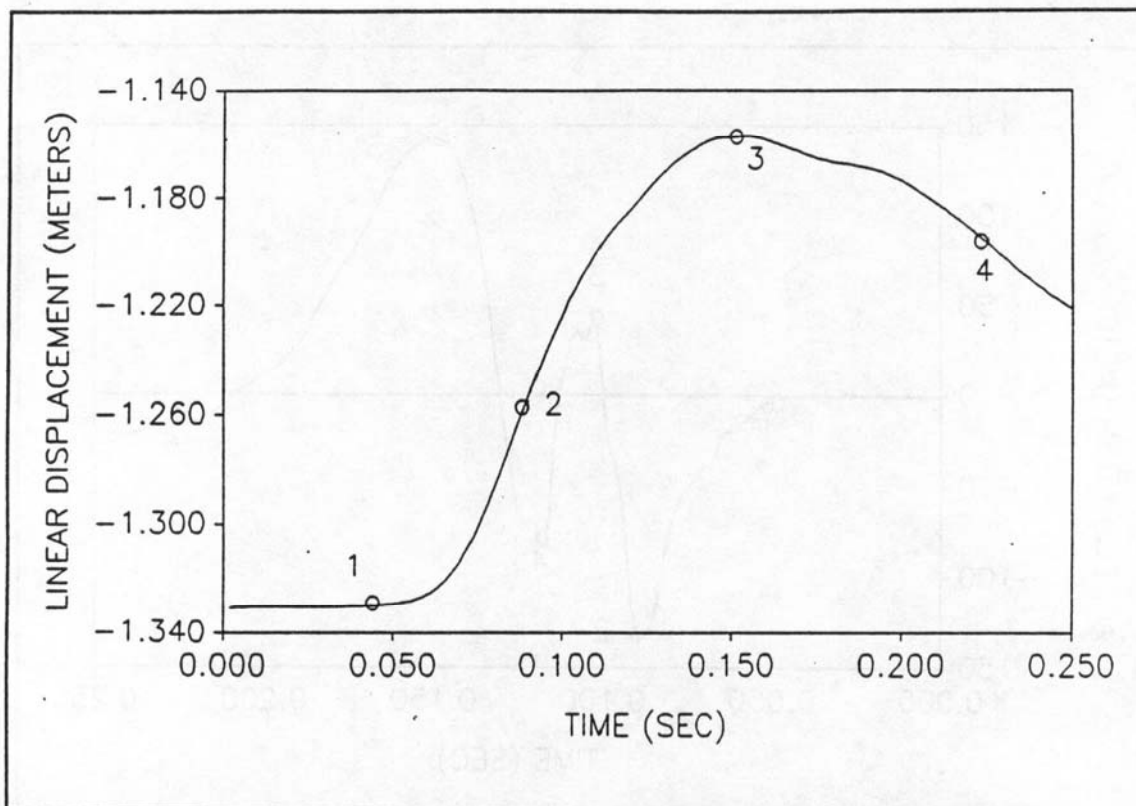


Figure 19. Onset, primary peak and offset points chosen for modelling the X-component of head linear displacement for 15g, -X human run.

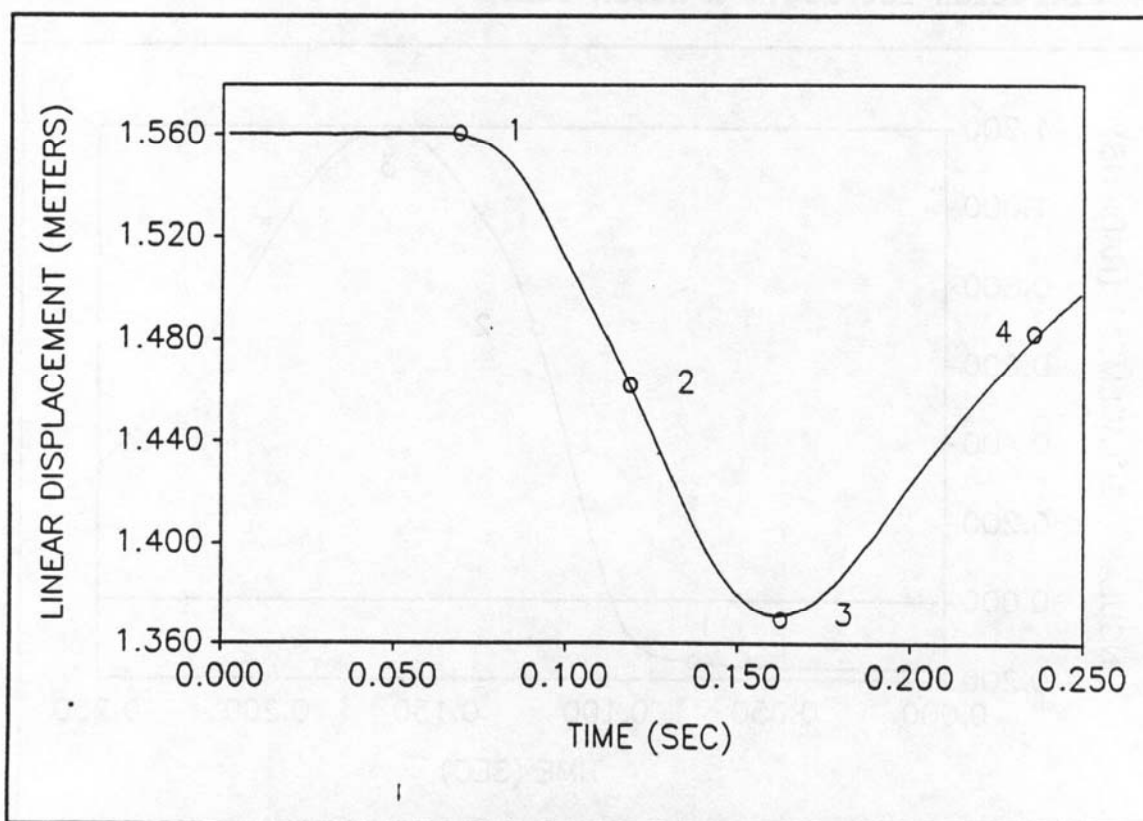


Figure 20. Onset, primary peak and offset points chosen for modelling the Z-component of head linear displacement for 15g, -X human run.

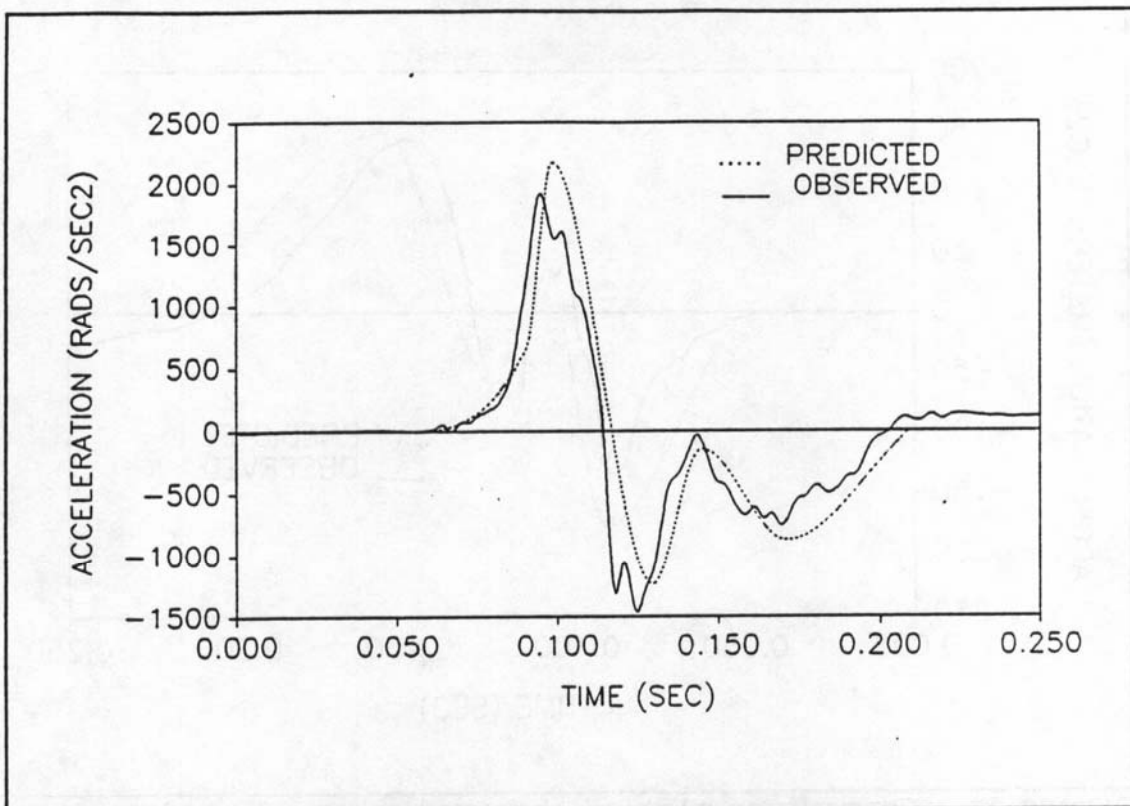


Figure 21. Comparison plot of observed and predicted response for the Y-axis component of head angular acceleration for 15g, -X human run.

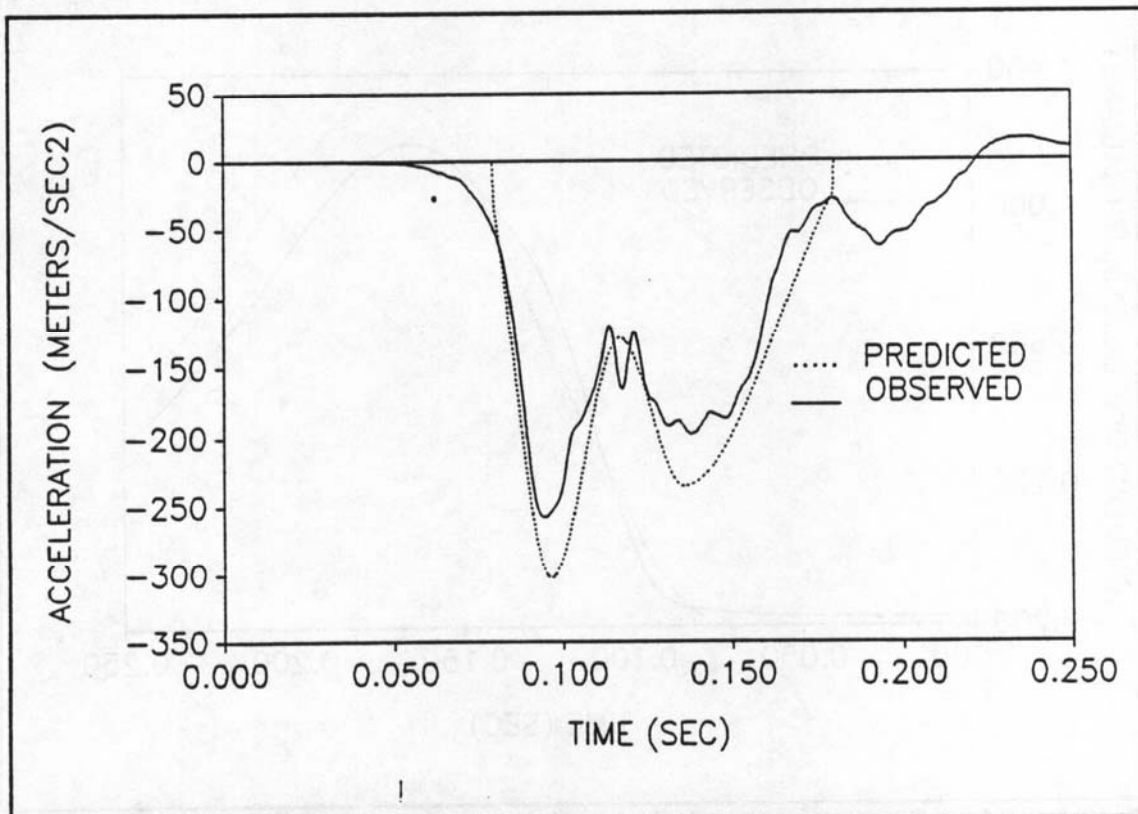


Figure 22. Comparison plot of observed and predicted response for the X-component of head linear acceleration for 15g, -X human run.

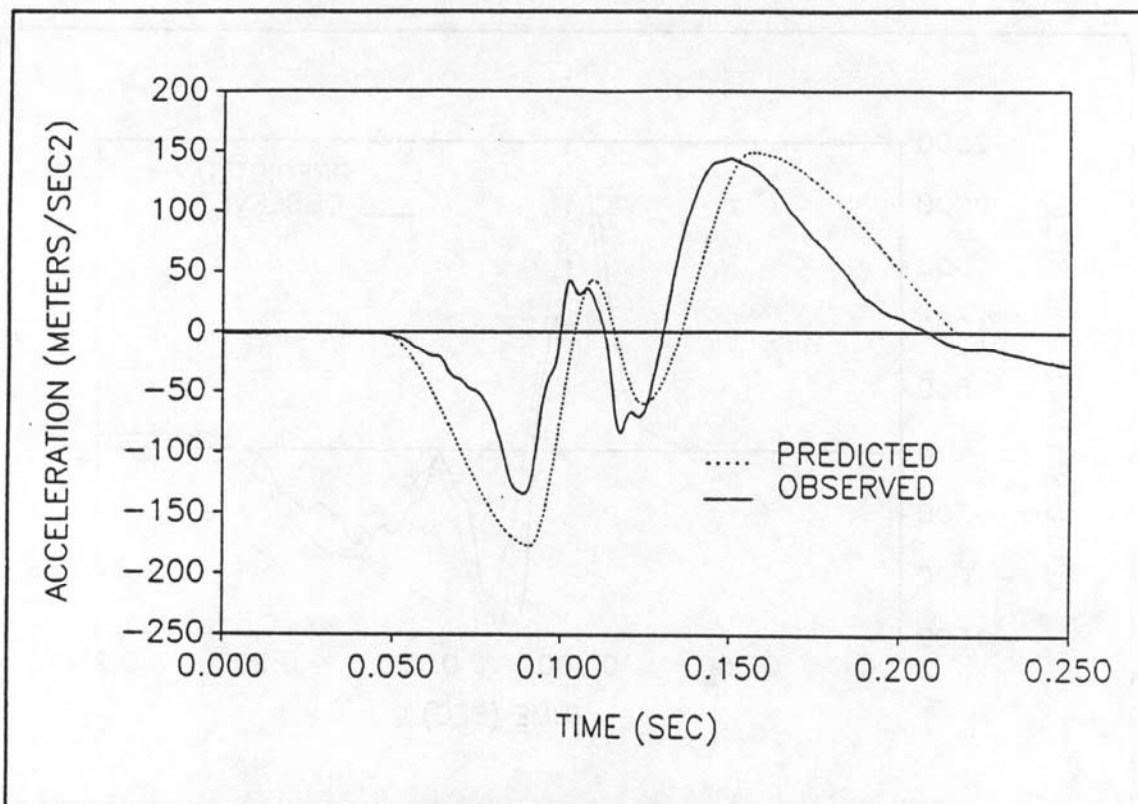


Figure 23. Comparison plot of observed and predicted response for Z-component of head linear acceleration, 15g, -X human run.

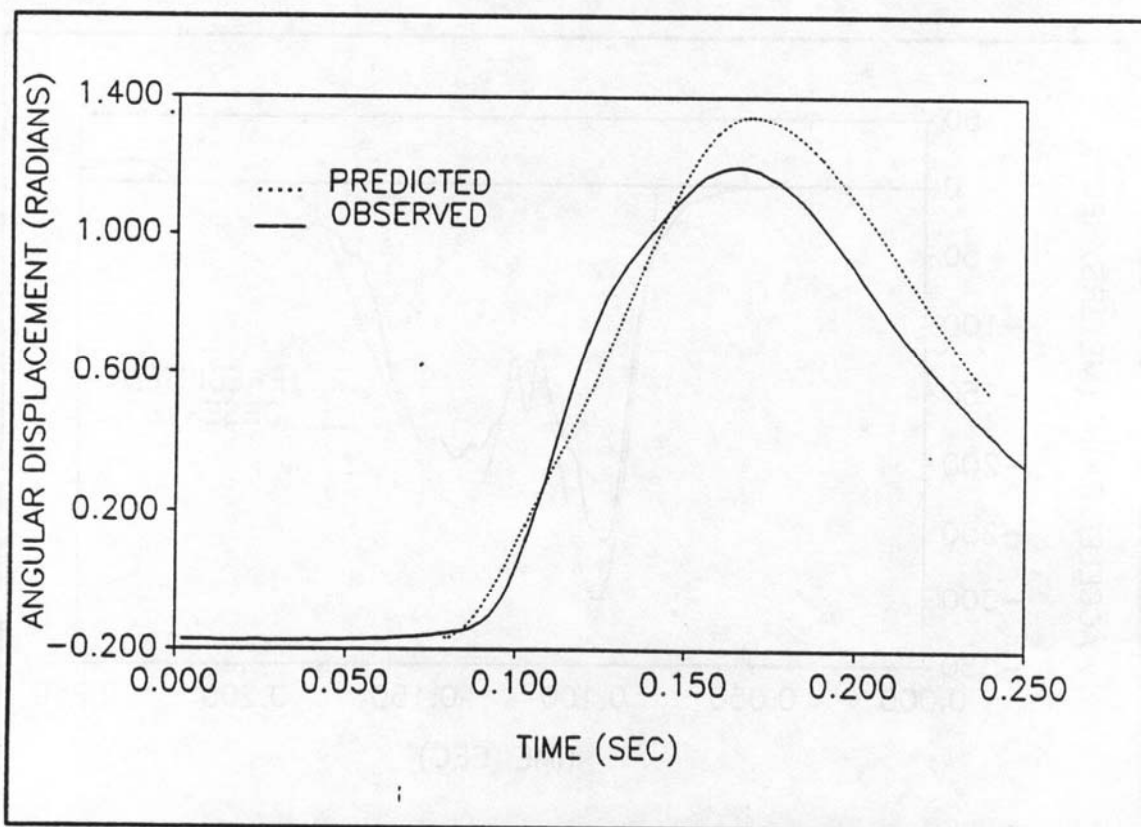


Figure 24. Comparison plot of observed and predicted response for the Y-axis component of head angular displacement for 15g, -X human run.

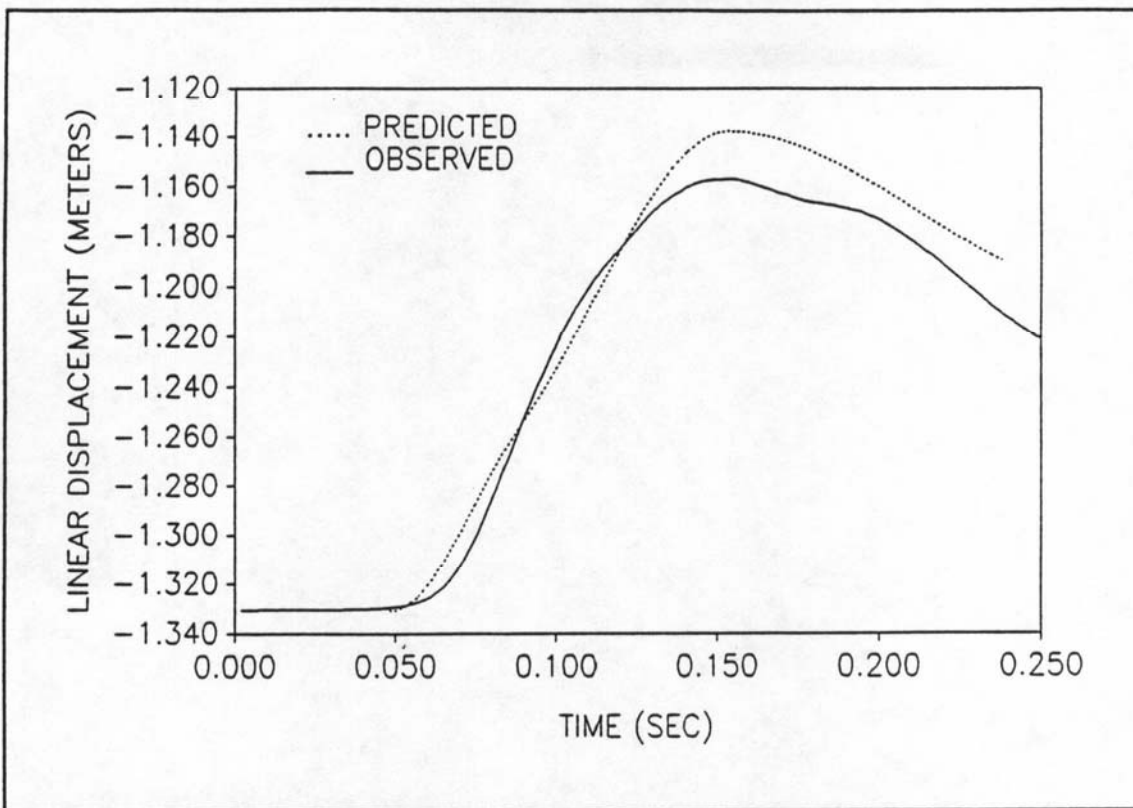


Figure 25. Comparison plot of observed and predicted response for the X-component of head linear displacement for 15g, -X human run.

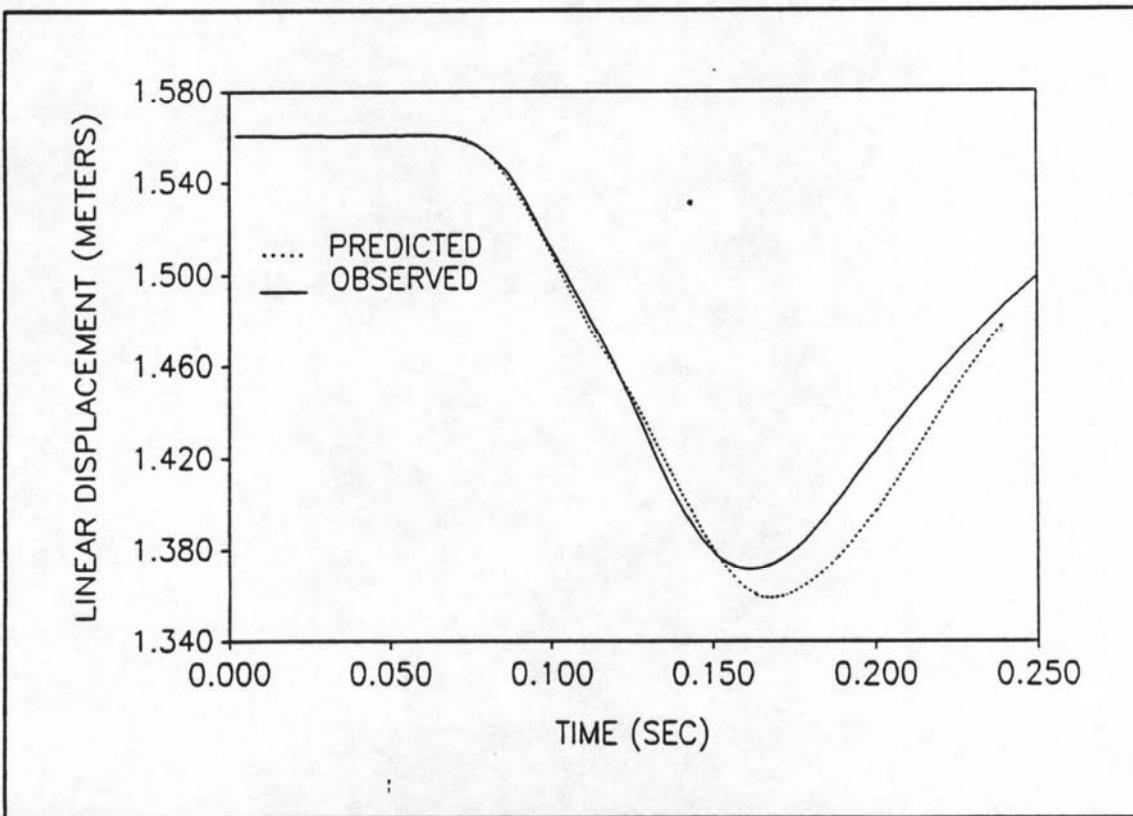


Figure 26. Comparison plot of observed and predicted response for the Z-component of head linear displacement for 15g, -X human run.

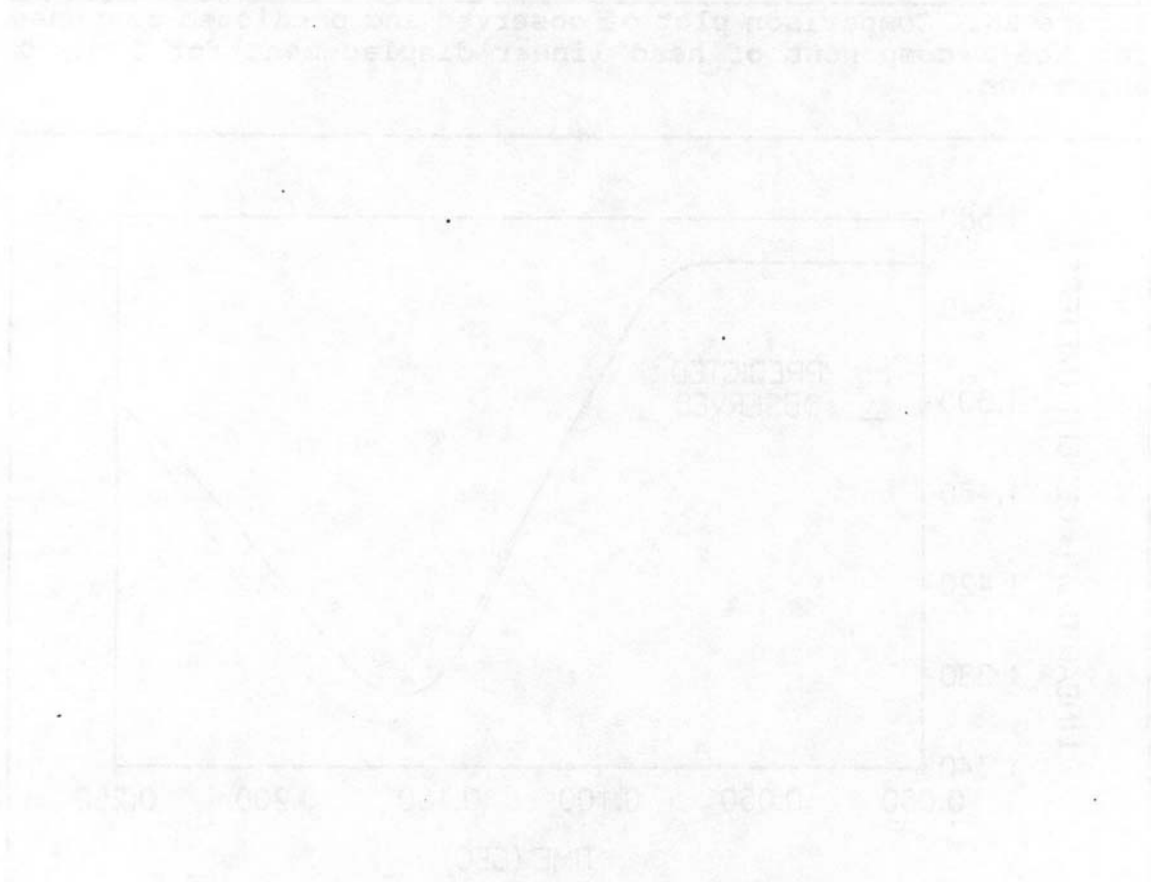
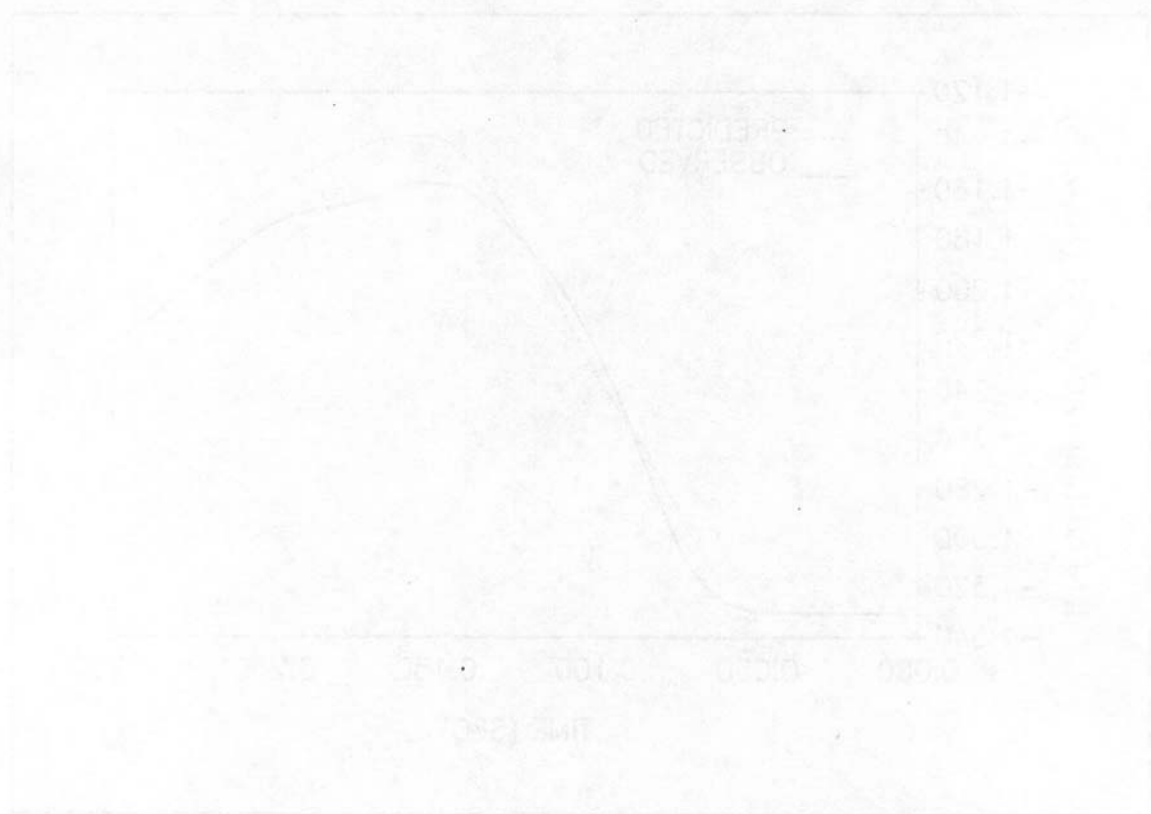


Figure 1. Comparison of predicted and observed values for the first set of data. The predicted values are shown as a solid line and the observed values as a dashed line. The predicted values are generally higher than the observed values, especially in the middle of the time range.

DISCUSSION

PAPER: Statistical Approach to Human Kinematic Response to Impact

SPEAKER: Terry Watkins, Naval Biodynamics Lab

No questions.

DISCUSSION

The first of the two main points of the paper is that the

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